FIGURE 1

ON-BOARD PROGNOSTIC INSTRUMENT ENGINEER (OPIE)

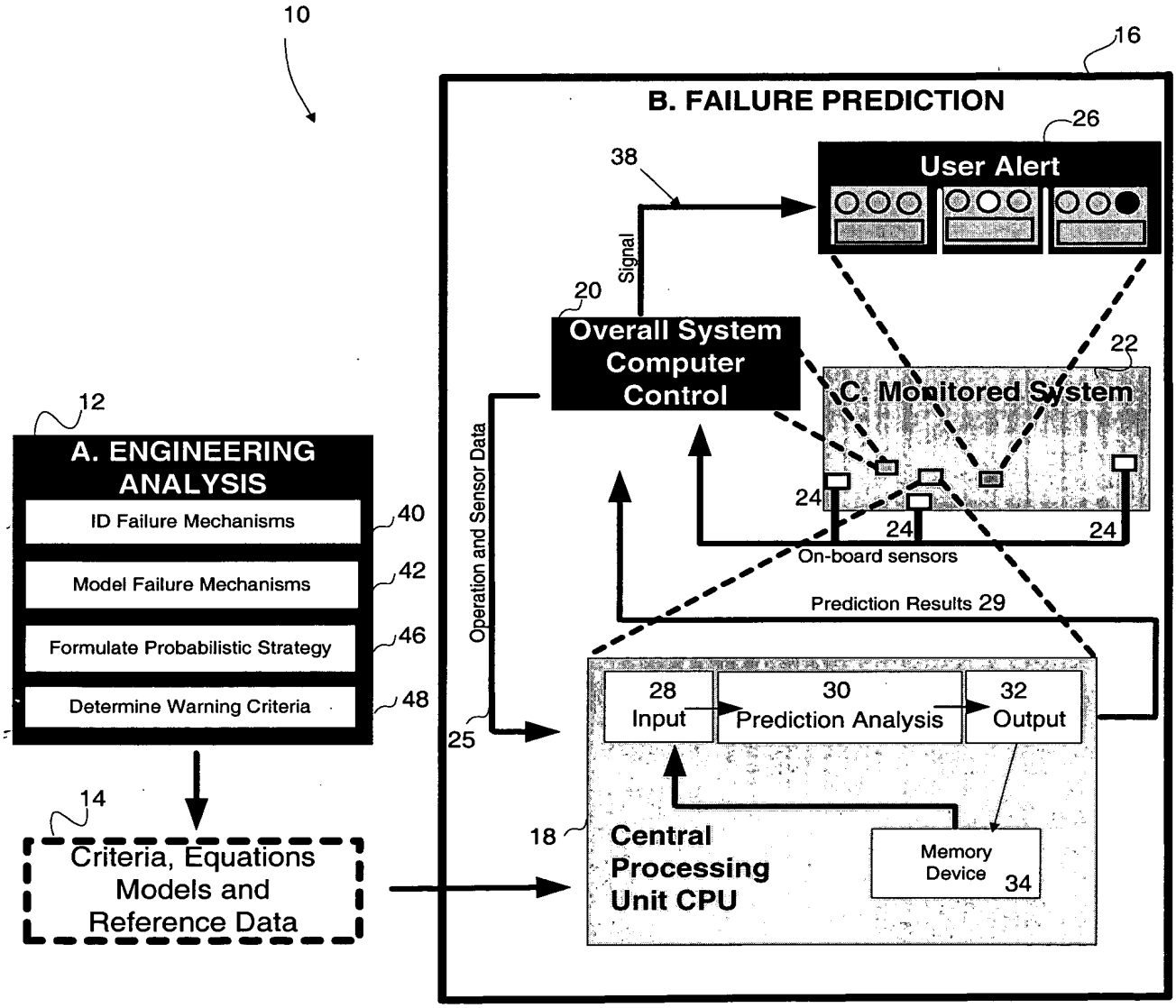


Figure 2A

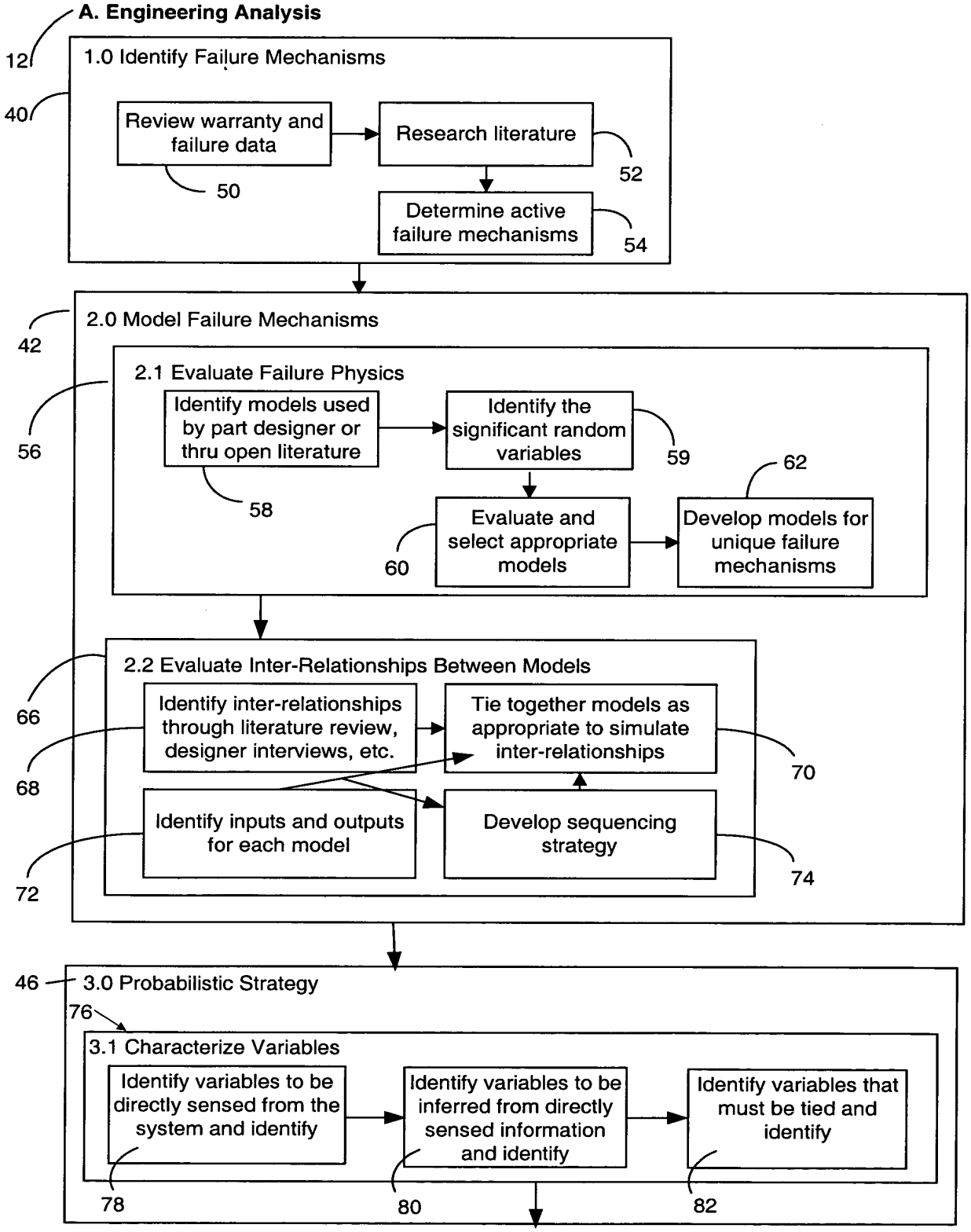

A. Engineering Analysis
12
1.0 Identify Failure Mechanisms
40
Review warranty and failure data
50
Research literature
52
Determine active failure mechanisms
54
2.0 Model Failure Mechanisms
42
2.1 Evaluate Failure Physics
56
Identify models used by part designer or thru open literature
58
Identify the significant random variables
59
62
Evaluate and select appropriate models
60
Develop models for unique failure mechanisms
2.2 Evaluate Inter-Relationships Between Models
66
Identify inter-relationships through literature review, designer interviews, etc.
68
Tie together models as appropriate to simulate inter-relationships
70
Identify inputs and outputs for each model
72
Develop sequencing strategy
74
46
3.0 Probabilistic Strategy
76
3.1 Characterize Variables
Identify variables to be directly sensed from the system and identify
78
Identify variables to be inferred from directly sensed information and identify
80
Identify variables that must be tied and identify
82

Figure 2B

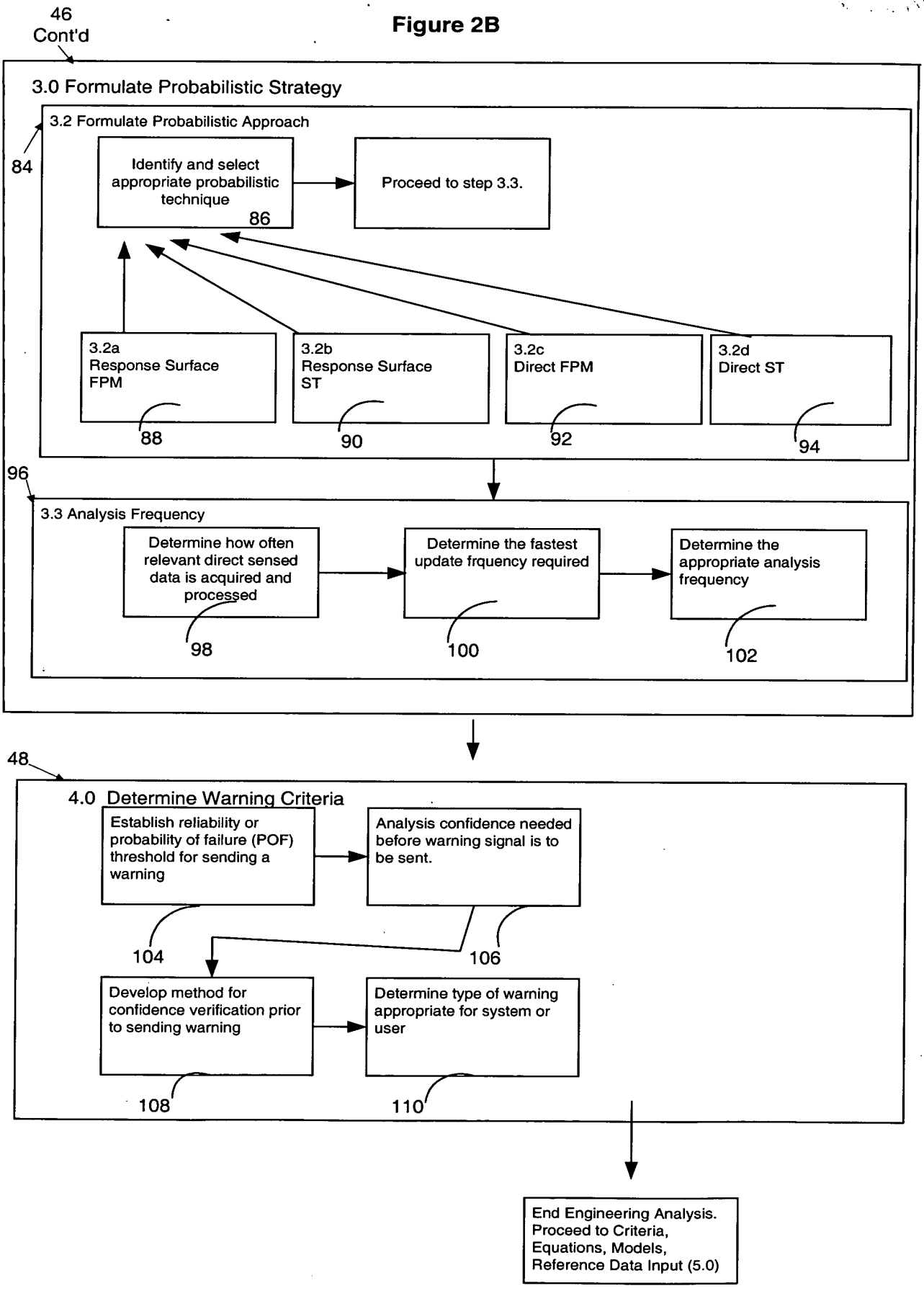

46
Cont'd
3.0 Formulate Probabilistic Strategy
3.2 Formulate Probabilistic Approach
84
Identify and select appropriate probabilistic technique
86
Proceed to step 3.3.
3.2a
Response Surface
FPM
88
3.2b
Response Surface
ST
90
3.2c
Direct FPM
92
3.2d
Direct ST
94
96
3.3 Analysis Frequency
Determine how often relevant direct sensed data is acquired and processed
98
Determine the fastest update frquency required
100
Determine the appropriate analysis frequency
102
48
4.0 Determine Warning Criteria
Establish reliability or probability of failure (POF) threshold for sending a warning
104
Analysis confidence needed before warning signal is to be sent.
106
Develop method for confidence verification prior to sending warning
108
Determine type of warning appropriate for system or user
110
End Engineering Analysis. Proceed to Criteria, Equations, Models, Reference Data Input (5.0)

FIGURE 2C

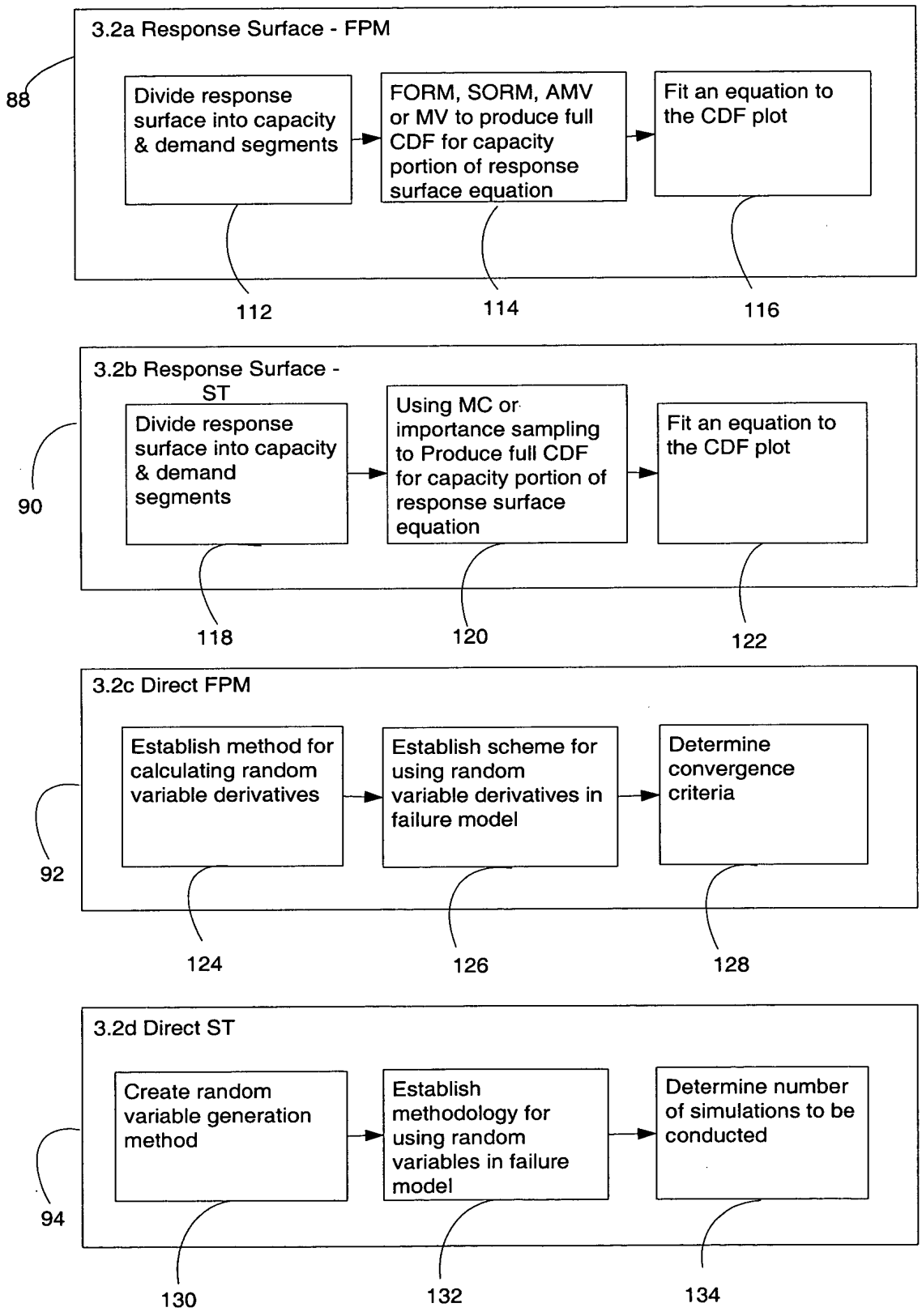

3.2a Response Surface - FPM
88
Divide response surface into capacity & demand segments
FORM, SORM, AMV or MV to produce full CDF for capacity portion of response surface equation
Fit an equation to the CDF plot
112
114
116
3.2b Response Surface - ST
90
Divide response surface into capacity & demand segments
Using MC or importance sampling to Produce full CDF for capacity portion of response surface equation
Fit an equation to the CDF plot
118
120
122
3.2c Direct FPM
92
Establish method for calculating random variable derivatives
Establish scheme for using random variable derivatives in failure model
Determine convergence criteria
124
126
128
3.2d Direct ST
94
Create random variable generation method
Establish methodology for using random variables in failure model
Determine number of simulations to be conducted
130
132
134

Figure 2D

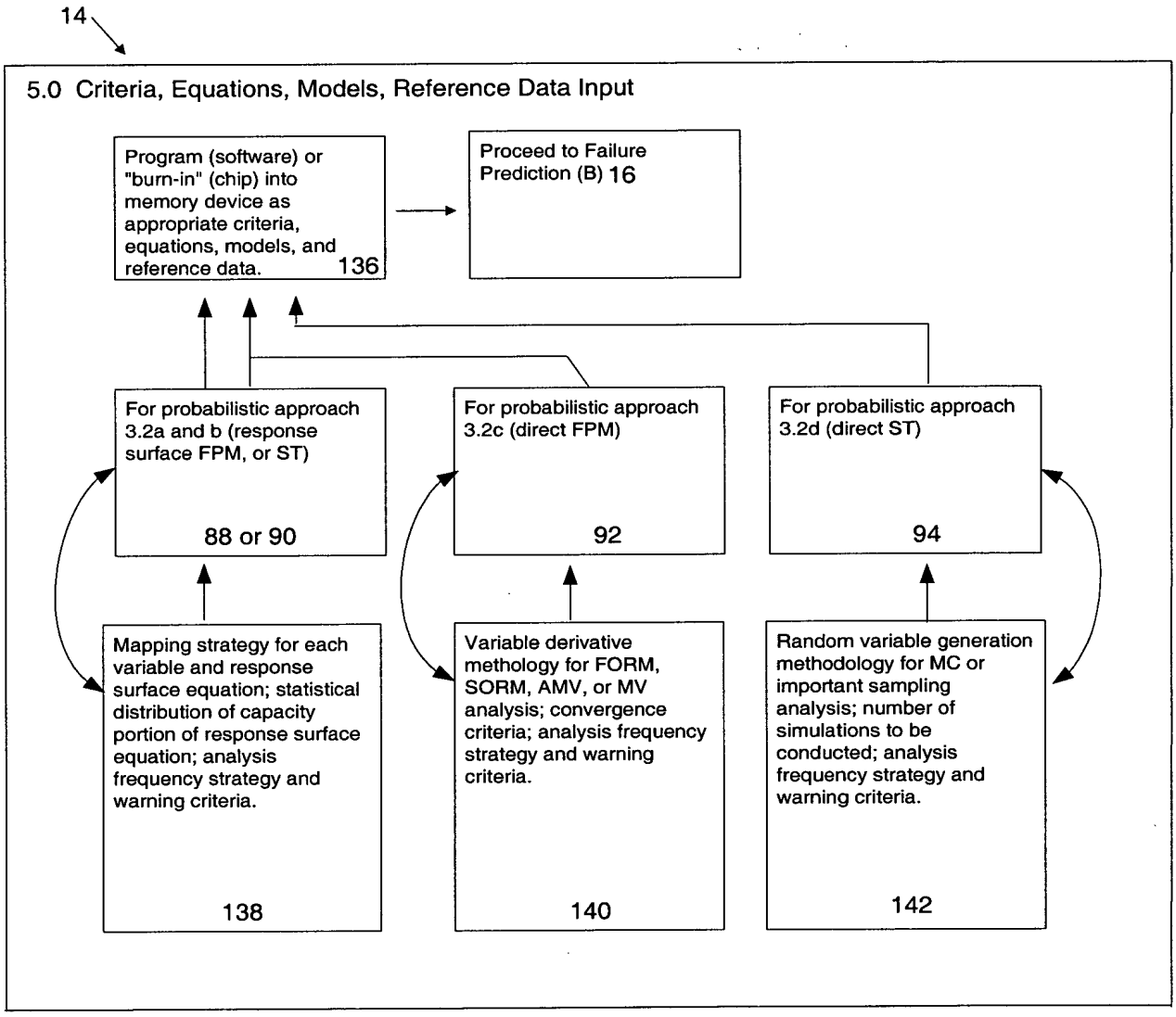

14
5.0 Criteria, Equations, Models, Reference Data Input
Program (software) or "burn-in" (chip) into memory device as appropriate criteria, equations, models, and reference data. 136
Proceed to Failure Prediction (B) 16
For probabilistic approach 3.2a and b (response surface FPM, or ST)
88 or 90
For probabilistic approach 3.2c (direct FPM)
92
For probabilistic approach 3.2d (direct ST)
94
Mapping strategy for each variable and response surface equation; statistical distribution of capacity portion of response surface equation; analysis frequency strategy and warning criteria.
138
Variable derivative methology for FORM, SORM, AMV, or MV analysis; convergence criteria; analysis frequency strategy and warning criteria.
140
Random variable generation methodology for MC or important sampling analysis; number of simulations to be conducted; analysis frequency strategy and warning criteria.
142

Figure 3A

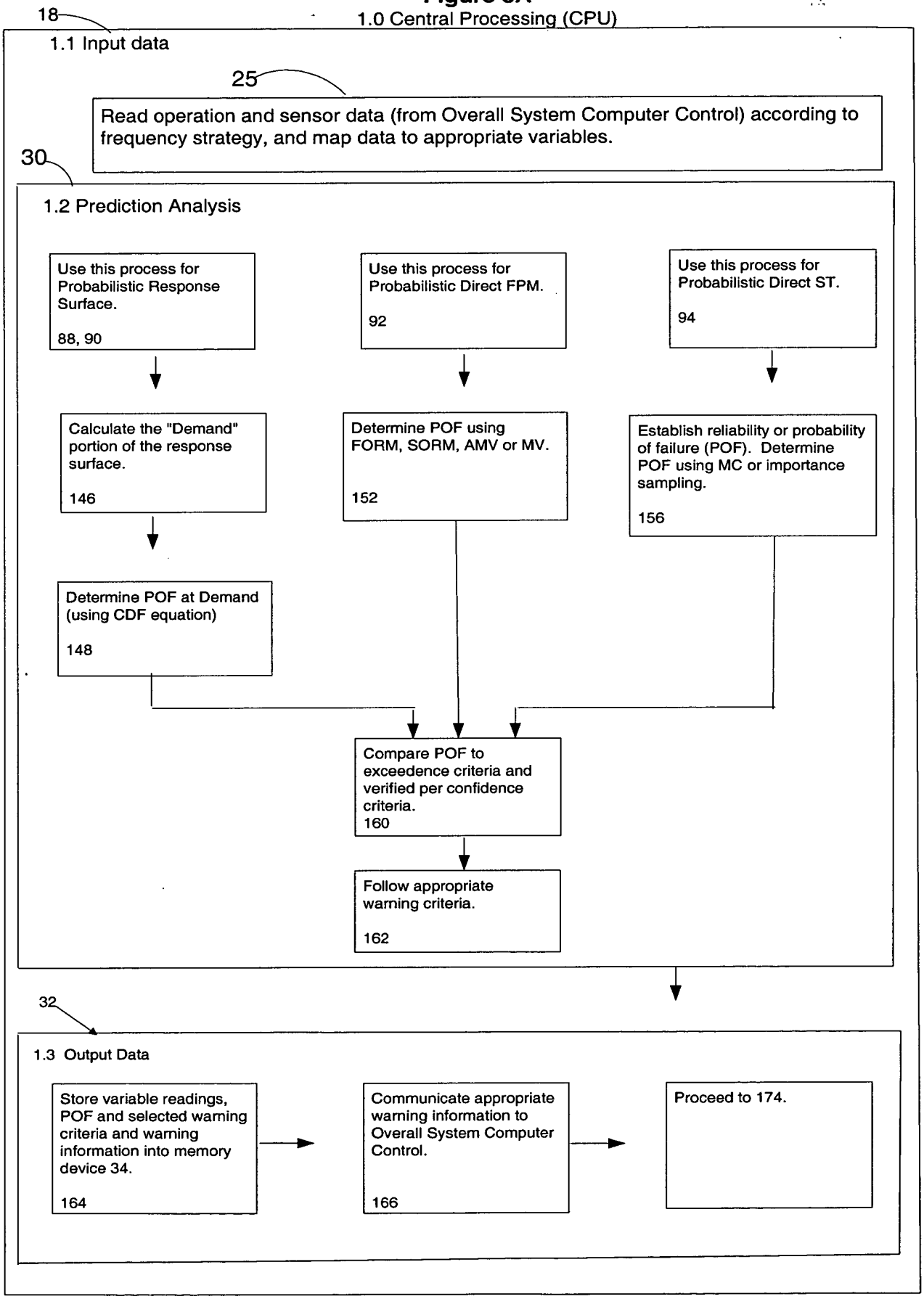

18
1.0 Central Processing (CPU)
1.1 Input data
25
Read operation and sensor data (from Overall System Computer Control) according to frequency strategy, and map data to appropriate variables.
30
1.2 Prediction Analysis
Use this process for Probabilistic Response Surface.
88, 90
Use this process for Probabilistic Direct FPM.
92
Use this process for Probabilistic Direct ST.
94
Calculate the "Demand" portion of the response surface.
146
Determine POF using FORM, SORM, AMV or MV.
152
Establish reliability or probability of failure (POF). Determine POF using MC or importance sampling.
156
Determine POF at Demand (using CDF equation)
148
Compare POF to exceedence criteria and verified per confidence criteria.
160
Follow appropriate warning criteria.
162
32
1.3 Output Data
Store variable readings, POF and selected warning criteria and warning information into memory device 34.
164
Communicate appropriate warning information to Overall System Computer Control.
166
Proceed to 174.

Figure 3B

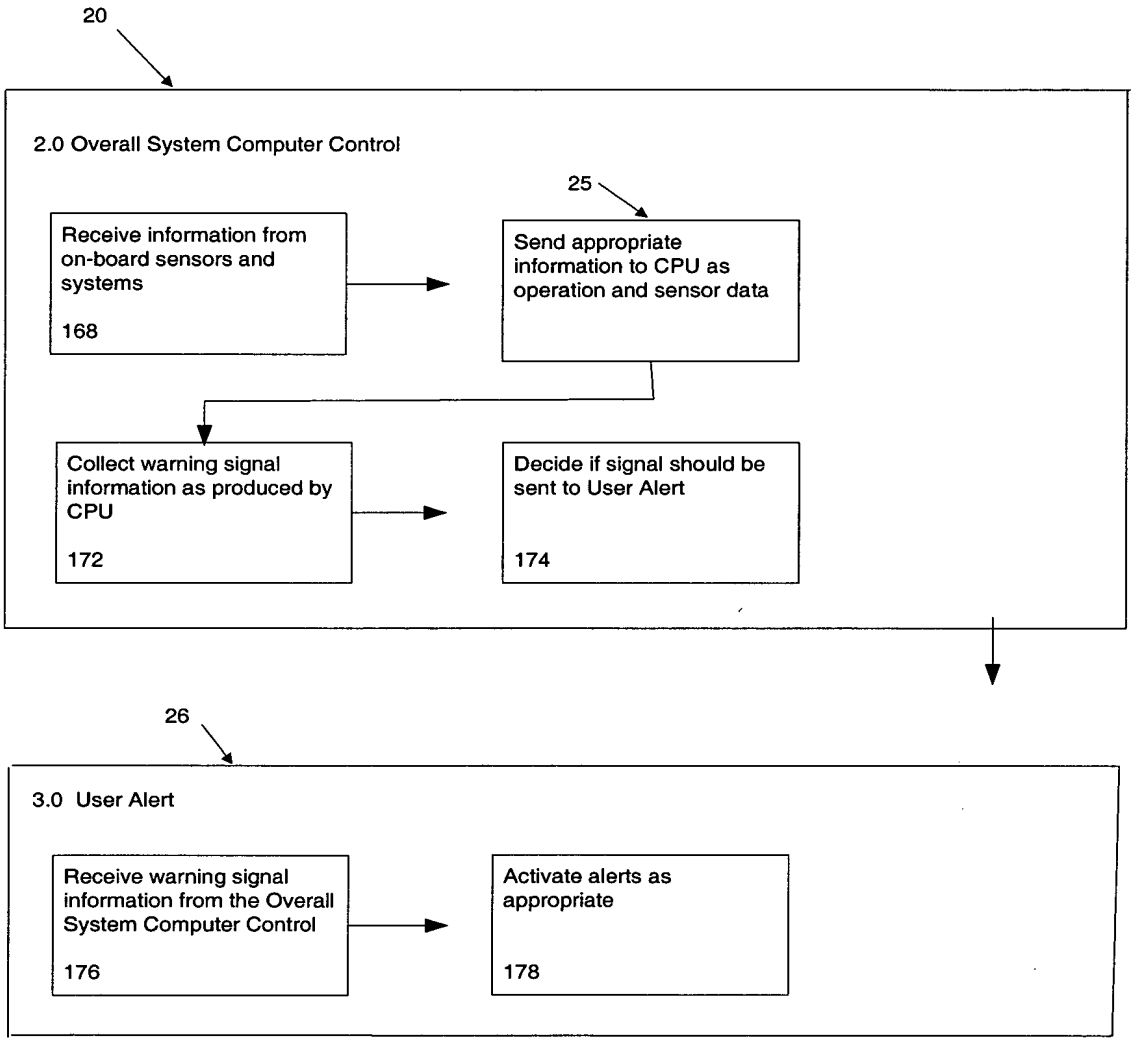
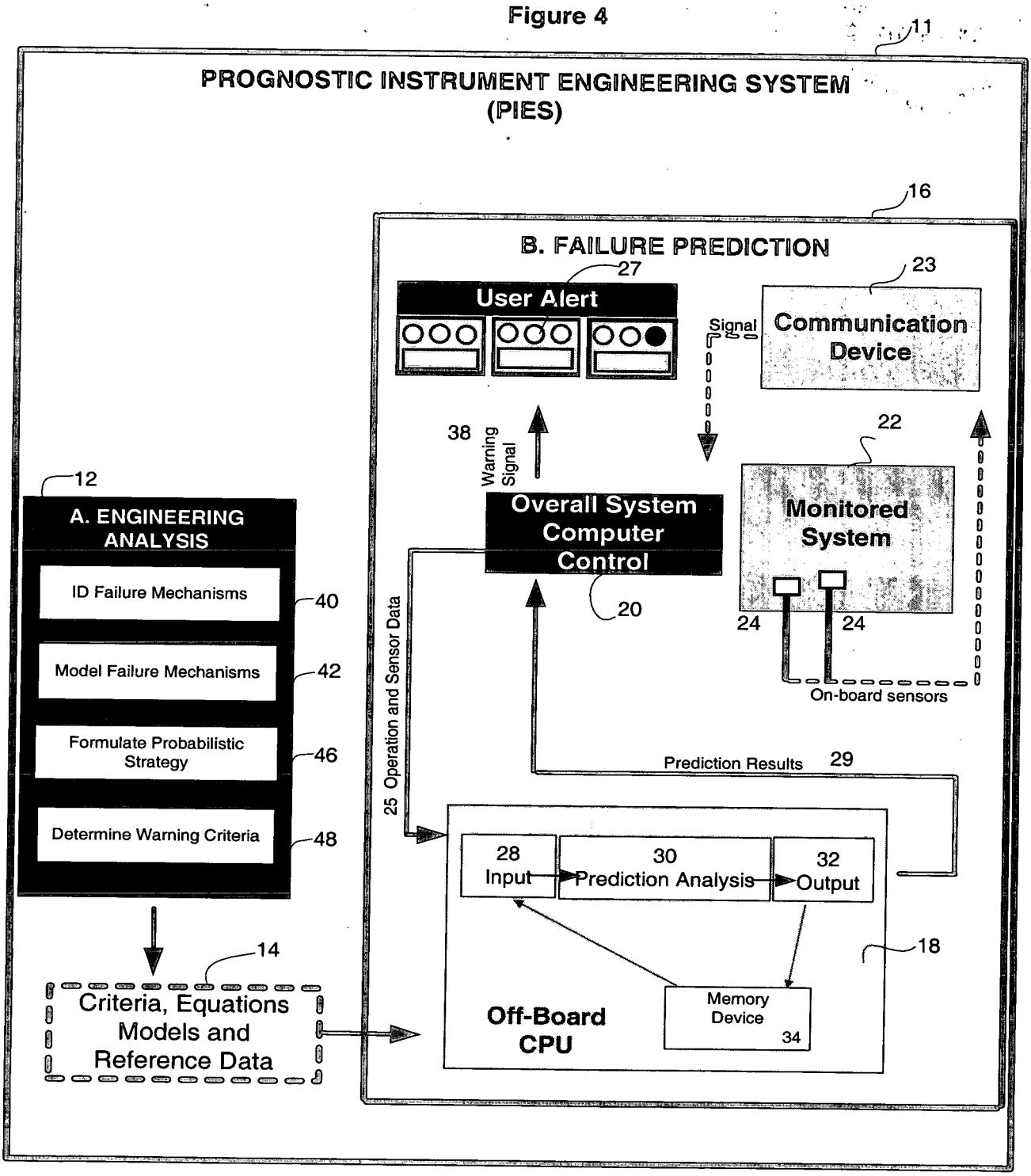

20
2.0 Overall System Computer Control
25
Receive information from on-board sensors and systems
168
Send appropriate information to CPU as operation and sensor data
Collect warning signal information as produced by CPU
172
Decide if signal should be sent to User Alert
174
26
3.0 User Alert
Receive warning signal information from the Overall System Computer Control
176
Activate alerts as appropriate
178

Figure 4


11
PROGNOSTIC INSTRUMENT ENGINEERING SYSTEM (PIES)
16
B. FAILURE PREDICTION
27
User Alert
23
Communication Device
Signal
38
Warning Signal
22
Monitored System
12
A. ENGINEERING ANALYSIS
Overall System Computer Control
20
ID Failure Mechanisms
40
Model Failure Mechanisms
42
Formulate Probabilistic Strategy
46
Determine Warning Criteria
48
24
24
On-board sensors
25 Operation and Sensor Data
Prediction Results
29
28 Input
30 Prediction Analysis
32 Output
18
14
Criteria, Equations Models and Reference Data
Off-Board CPU
Memory Device
34

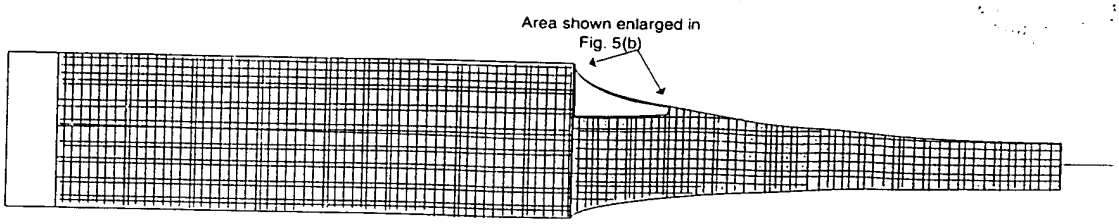


Figure 5(a)

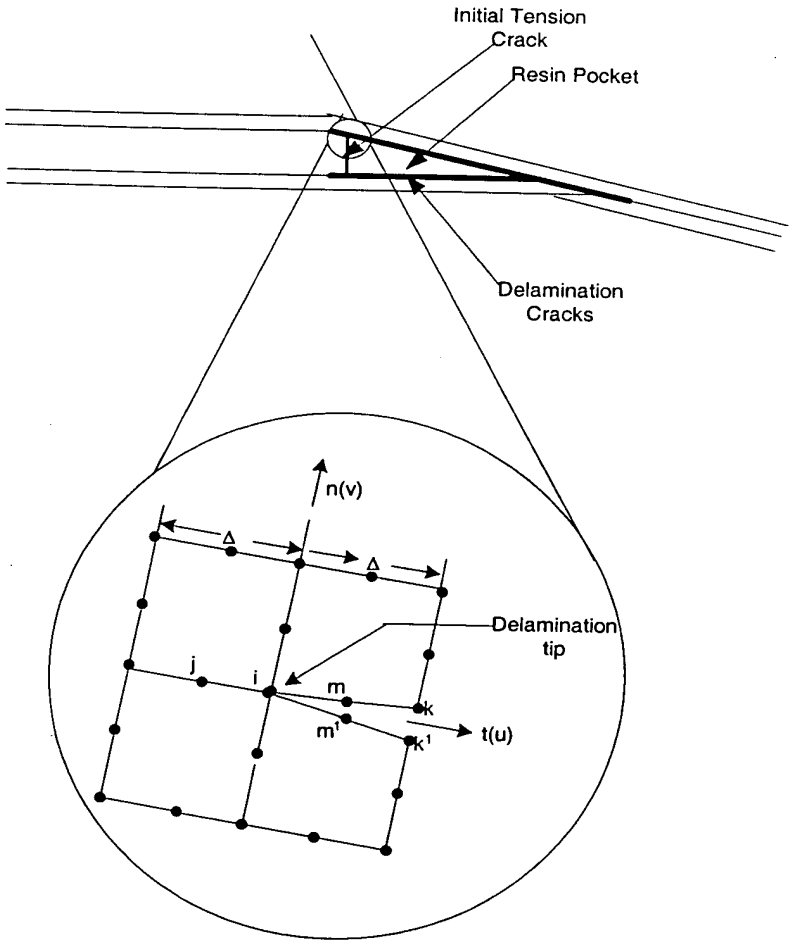


Figure 5(b)

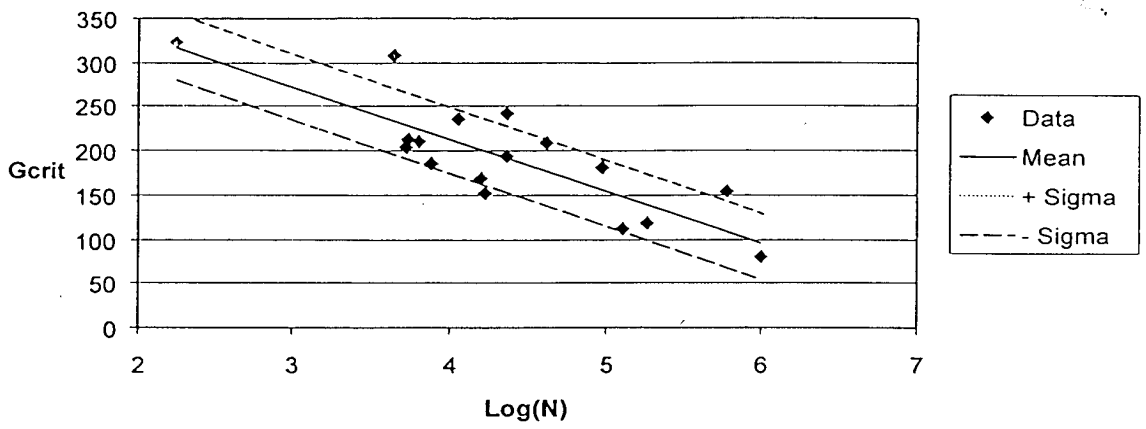


Figure 5(c)

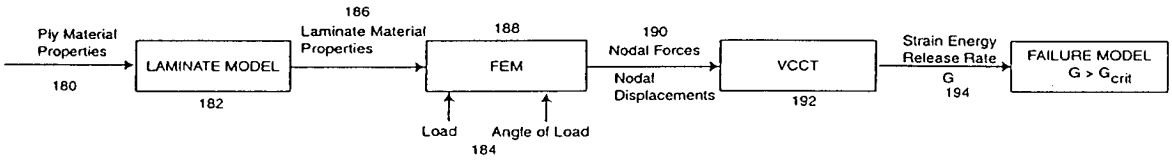


Figure 5(d)

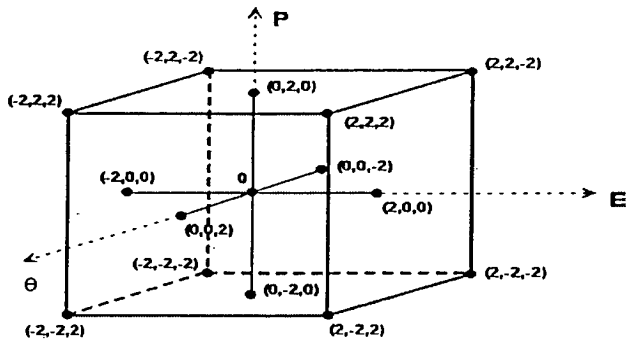


Figure 5(e)

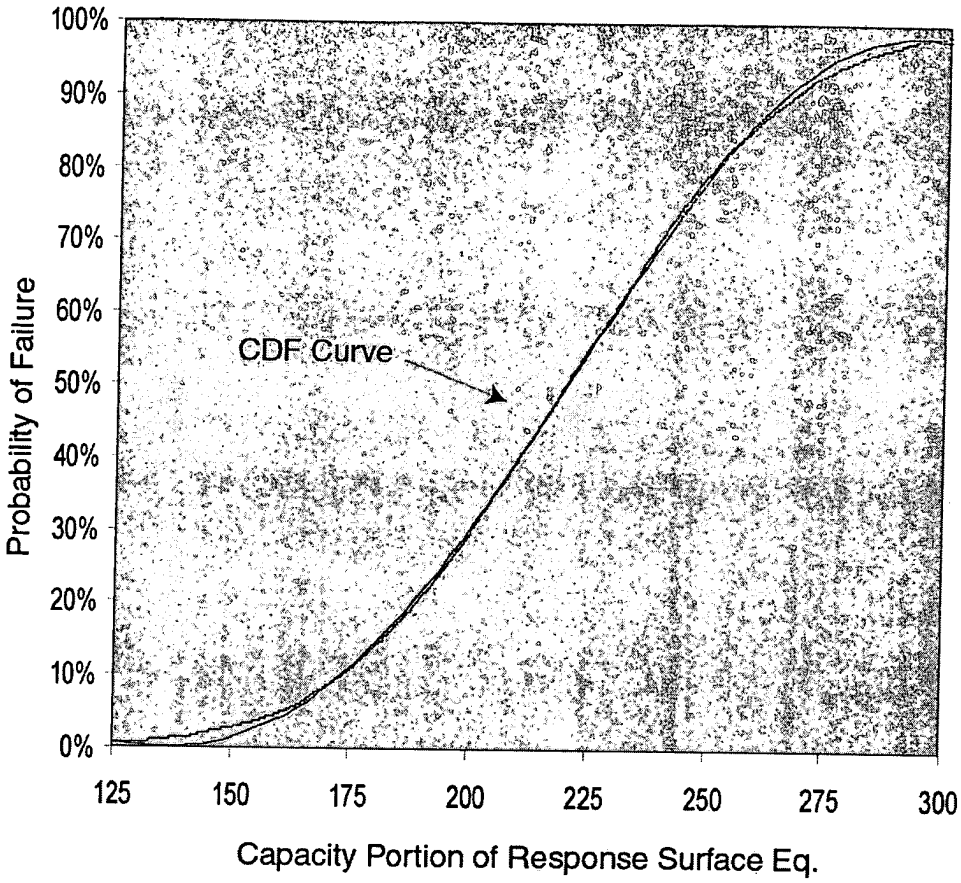

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Probability of Failure
CDF Curve
125
150
175
200
225
250
275
300
Capacity Portion of Response Surface Eq.

Figure 5(f)